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ARMY RESEARCH LABORATORY

Test Comparison for 20mm Perforated Muzzle Brakes

Douglas S. Savick

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13. ABSTRACT *(Maximum 200 words)*

Tests were conducted at the Ballistic Research Laboratory for a 20mm perforated muzzle brake. Six muzzle brake designs were analyzed for their influence on muzzle velocity, blast overpressure, and brake efficiency. The designs were a combination of scaled versions of 105mm and 120mm muzzle brakes and new designs that were fabricated to reduce blast overpressure at the breech. Certain designs were tested to verify computer predictions that upstream venting in a muzzle brake could reduce the blast overpressure at the breech.

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PREFACE

The U.S. Army Ballistic Research Laboratory was deactivated on 30 September 1992 and subsequently became a part of the U.S. Army Research Laboratory (ARL) on 1 October 1992.

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1. Introduction

A series of tests were performed at the Ballistic Research Laboratory (BRL) on a 20mm perforated muzzle brake. The tests were conducted for Benet Weapons Laboratory (BWL) to verify computer predictions that upstream venting could reduce peak blast overpressure near the breech of a gun.[1] It is claimed that the blast wave from the perforated muzzle brake interferes with the main blast and reduces its strength.

This report will contain a description of the test setup and a detailed analysis of the following areas of the 20mm perforated muzzle brakes:

- Muzzle Velocity
- Blast Overpressure
- Shadowgraphs
- Recoil Attenuation

2. Test Setup

The test was performed at BRL's indoor Aerodynamics Range.[2] A schematic drawing of the test setup is shown in Figure 1. An actual photograph of the test setup is shown in Figure 2. Most of the instrumentation is contained in the area called the blast room. Velocity screens are located further down range.

Perforated muzzle brake designs from 105mm and 120mm tests were scaled down for the 20mm gun to verify their efficiency. A total of six brakes were tested. The devices, seen in Figure 3, were designed and fabricated to be screwed on to a 20mm Mann barrel that was threaded at the muzzle. A seventh device was used to represent a bare muzzle, having the same length as the other six devices (approx. 28 cm) but no perforations. The bare muzzle device was used as a baseline for the six designs. Ammunition used for this test was Cartridge, 20mm, TP, M55A2. Comparisons being made with the 105mm and 120mm brakes are results using Cartridge, 105mm, TP-T, M490 and Cartridge, 120mm, HEAT-TP-T, M831 ammunition.

Figure 3, viewing from left to right, shows devices 1 through 7. Devices 2, 3, and 4 were designs tested for the 120mm gun. Devices 6 and 7 were tested for the 105mm gun. Device 5 is the scaled down version of the EX35 perforated muzzle brake design that is used for the 105mm gun. The EX35 is being supplied as government furnished equipment for the Armored Gun System which is currently in full development. Device 7 was of special interest because of its unique design as being a "split brake" (perforations are spaced apart). Drawings for the six designs can be seen respectively in Figures 4-9.

[1] Carofano, G.C., "Blast Field Contouring Using Upstream Venting", 4th International Symposium on Computational Fluid Dynamics, U. of California-Davis, Davis, California, September 9-12, 1991.

[2] Braun, W.F., "The Free Flight Aerodynamics Range," BRL-R-1048, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, August 1958. (AD 202249)

Piezoelectric gages were suspended from above the muzzle to measure the blast overpressure at seven stations located at the following angles from the line of fire in front of the muzzle: 15°, 30°, 60°, 90°, 120°, 150°, and 165°. The gages measured pressure at distances of 30, 40, and 50 calibers from the muzzle. The gun barrel was mounted on a free recoil mount that offered negligible resistance to the recoiling gun. Attached to the gun mount was an LVDT (Linear Variable Differential Transformer) measuring device that sensed the distance traveled by the gun mount in time. From this measurement, the recoil velocity could be obtained. Two x-rays were used side by side to capture the projectile image at two predetermined times on the same piece of film. A fiducial was also exposed on the film at the same time to determine the distance between them. From this, the muzzle velocity could be determined. Further down range, velocity screens were used as another method to measure velocity. Finally, a Fresnel lens was used to aid photographing the shadow of the projectile and/or the blast wave.

A piezoelectric gage was placed at the muzzle to trigger on the main blast and provide a zero time. A delay generator was used to trigger the instrumentation at the appropriate time. Nicolet oscilloscopes recorded the required data.

3. Muzzle Velocity

The purpose for recording muzzle velocity was to determine if any or all of the muzzle brakes affected it. From Savick and Baur,[3] the 120mm perforated muzzle brake decreased the muzzle velocity by approximately 2%.

Muzzle velocity was not determined for every round fired since x-rays were not used for each shot. Two muzzle velocities were recorded for each muzzle device. These velocities were averaged for each device and are provided in Table 1. The light screen velocities were recorded for all rounds fired. Though this sample is not the same as the muzzle velocity (velocity loss over distance due to drag) it is acceptable for comparison between devices. The average velocities for the light screen are also provided in Table 1.

It was expected that this test would provide similar results for velocity loss in the perforated muzzle brakes as were found in the 105mm and 120mm tests. From Table 1, it is seen that there was an insignificant difference between the baseline velocity and the various brake velocities. The largest difference was .4% or 4 m/s. Comparison of muzzle velocities between muzzle devices was not attainable because of the inconsistency of the ammunition itself.[4] The standard deviation for the projectile velocities measured for the device 1 (no brake) was 4.5 m/s. Baur had also noted similar results in his work with muzzle velocity for muzzle brakes on a 5.56mm rifle.[5]

[3]Savick, D.S. and E.H. Baur, "120mm Perforated Muzzle Brake Performance", BRL Memorandum Report BRL-MR-3816, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, 1990 (Confidential)

[4]"Logistics - Complete Round Charts", DARCOM Pamphlet 700-3-2, U.S. Army Material Development and Readiness Command, Alexandria, Virginia 22333, May 1984.

[5]Baur, E.H. and J.C. Ford, "A Parametric Study of Muzzle Brakes for Small Caliber Automatic Rifles, BRL-TR-3234, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, May 1991.

4. Blast Overpressure

Muzzle brakes redirect the blast towards the breech raising the overpressure in that area, sometimes to dangerous levels. By measuring the blast overpressure distribution for each device at various positions around the muzzle, it can be determined how much the muzzle device increases pressure behind the gun relative to the bare muzzle. Pressure data were acquired with piezoelectric gages located at 15°, 30°, 60°, 90°, 120°, 150°, and 165° around the muzzle and measuring the pressure over a desired time period.

Pressure data were taken at each angle at three different distances from the muzzle: 30, 40, and 50 calibers. In accordance with the test plan given by BWL, pressure data were acquired for all devices at 30 calibers but only device 1, 5, and 7 were used to determine blast overpressure at 40 and 50 calibers. Figures 10, 11, and 12 show the peak overpressure for all three distances.

Observation of blast overpressure was concentrated mostly for devices 1, 5, and 7. In Figure 10, all seven devices are compared to each other with respect to device 1. As was expected, device 1 had the highest peak overpressure in front of the muzzle and the lowest at the breech. Muzzle brakes generally decrease the pressure in the front of the muzzle but increase it towards the rear. Device 5 performed the same as most of the other devices. Device 7 showed somewhat lower pressure in the breech area than the other devices. Figures 11 and 12 show a comparison between devices 1, 5, and 7 at 40 and 50 calibers. Similar results are found for each device as found in Figure 10.

5. Shadowgraphs

Shadowgraphs were taken to provide a qualitative description of the blast wave. To produce a shadowgraph, the shadow of the blast wave was projected through a Fresnel lens and acquired by a camera. The blast room was darkened and the camera's shutter was left open. A light source was illuminated at a desired time after the instrumentation was triggered. The pressure signal from the muzzle gage triggered a delay generator which in turn triggered the light source to capture a shadowgraph at the desired location of the blast wave. For certain muzzle devices, the blast wave was photographed up to 1.5 m (5 ft) behind the muzzle at increments of 15 cm (6 in) from the muzzle.

Shadowgraphs were taken to qualitatively observe the blast pressure wave as it travels rearward from the muzzle. Figure 13 shows an example of the blast wave. In this particular photograph initially, the gases exit out the muzzle brake and then the muzzle. Two individual blast waves are formed. Eventually, the muzzle blast wave overtakes the muzzle brake blast wave as they travel toward the breech. During the period of testing, shadowgraphs were taken at various positions along the gun tube to observe the strength of the blast wave. Emphasis was placed on device 1, 5, and 7. Device 7, the split brake (Figure 14), was designed with the expectation that the rear most holes (two rows) would provide a weaker blast wave that would break up the approaching blast wave and reduce its strength thus reducing the pressure in the breech region.

Shadowgraphs pictorially display the blast wave at different positions along the gun barrel as it travels toward the breech. Figure 15 displays the blast wave from device 5 at 750 μs after the instrumentation had been triggered. Figure 16 shows the blast wave of device 7 at the same time delay as Figure 15. The blast wave from device 7 is seen to be further uprange than that from device 5 since the vent holes are further uprange. The blast wave does not appear to be as strong.

6. Recoil Attenuation

The main purpose of a muzzle brake is to reduce the momentum being applied to the recoil system. Muzzle brakes redirect a portion of the exiting gases to the side exerting a forward force on the brake, thus reducing recoil. The six devices were compared to determine their recoil efficiency.

The gun was mounted on a free recoil mount that allowed the gun to recoil with negligible resistance. The mount, shown in Figure 2, was seated on two shafts and traveled freely along them by use of ball bearings between the mount and the shafts. The mount stopped at a spring-damper at the end of the recoil travel and was manually reset for the next test round.

As the gun was fired, the mount movement was measured with respect to time. An LVDT (Linear Variable Differential Transformer) was used to measure the movement. The data were recorded on a Nicolet oscilloscope. The data were then differentiated to determine the recoil velocity.

As stated before, finding the brake efficiency of the muzzle brake was the main objective in performing these tests. In this report, brake efficiency will be defined in two ways. The first expression is the overall brake efficiency, which is the percent reduction in the recoil impulse due to the action of the muzzle brake. Represented by ψ it is defined as the following.

$$\psi = \frac{I_{wo} - I_w}{I_{wo}} \cdot 100\% \qquad (1)$$

I_{wo} symbolizes the total impulse of the gun without the brake and I_w is the total impulse of the gun with the brake. The second expression for recoil efficiency is the gas dynamic brake efficiency, β. This efficiency is a modification of the overall efficiency. It is the percentage of momentum extracted from the exhausting propellant gases. Defined as

$$\beta = \frac{I_{wo} - I_w}{I_{wo} - m_p V_e} \cdot 100\% \qquad (2)$$

m_p is the mass of the projectile and V_e is the projectile muzzle velocity. I_w and I_{wo} are determined by multiplying the mass of the recoiling unit by its velocity.

$$I = m_r V_r \qquad (3)$$

where m_r is the mass of the recoiling unit and V_r is the velocity of the recoiling unit. V_r was determined for each device by using the average of all the recoil velocities recorded while each device was tested.

The brake efficiencies are listed in Table 2. Most of the brakes had similar efficiencies with the devices 5 and 7 being somewhat better. Some results for the full scale 105mm and 120mm muzzle brake tests are also included in Table 2. For device 5, the overall efficiency was comparatively close to the 105mm results from Plostins and Clay.[6] Results from devices 2, 3, and 4 did not agree with results from the 120mm test.

This difference is attributed to a lack of resolution in the full scale tests. The 120mm muzzle brakes were fired from the M1A1 concentric recoil mount. Recoil impulse could not be directly measured in these tests, but had to be inferred from the integration of data such as breech pressure, recoil oil cylinder pressure, and gun displacement-time history. However, friction forces on the recoiling tube could not be measured and had to be inferred from other data. It is felt that this approximation resulted in an overestimation of brake efficiencies.

7. Summary and Conclusions

1. Muzzle velocity reduction due to the use of the muzzle brake could not be determined due to inconsistency of projectile velocity.

2. Device 7 showed the lowest peak overpressure at the breech.

3. Shadowgraphs show the blast wave to be weaker along the cannon for device 7 than blast waves of other devices.

4. Device 5 and device 7 had the highest brake efficiency of all devices tested.

5. The overall efficiency for the 20mm and the 105mm EX35 design were close in comparison to each other.

6. Results for devices 2, 3, and 4 did not agree in brake efficiency with the corresponding 120mm tests. It appears that the method for solving brake efficiency for the 120mm test needs refinement.

[6] Plostins, P. and Clay, W.H., "Performance of Light Weight 105 MM Cannon Designs", BRL Technical Report BRL-TR-2749, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. 21005-5066, 1986 (Confidential)

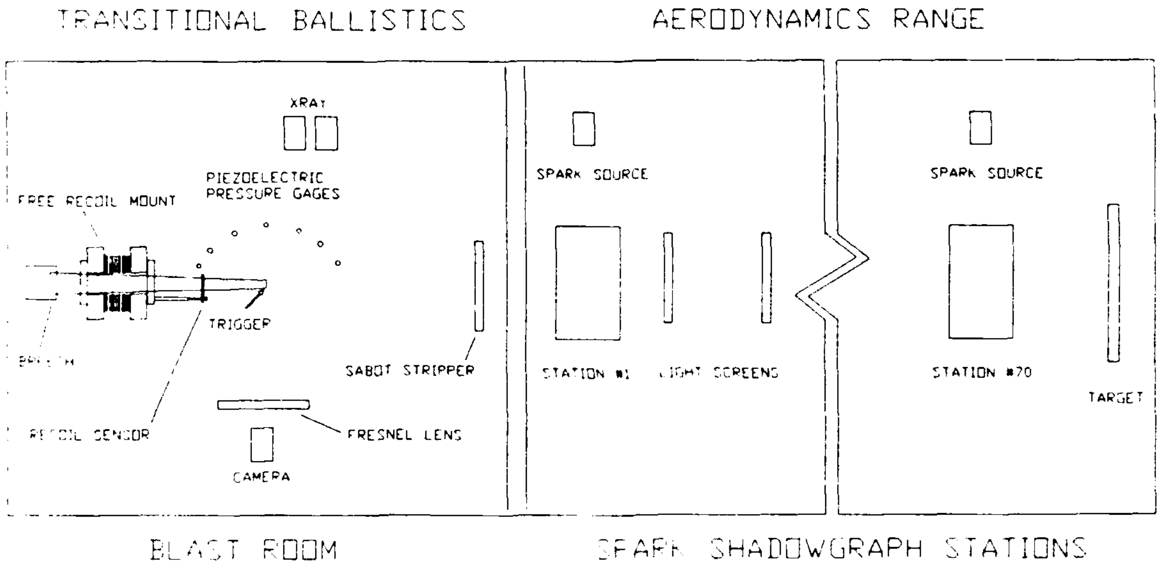

Figure 1. Schematic Drawing of Test Setup

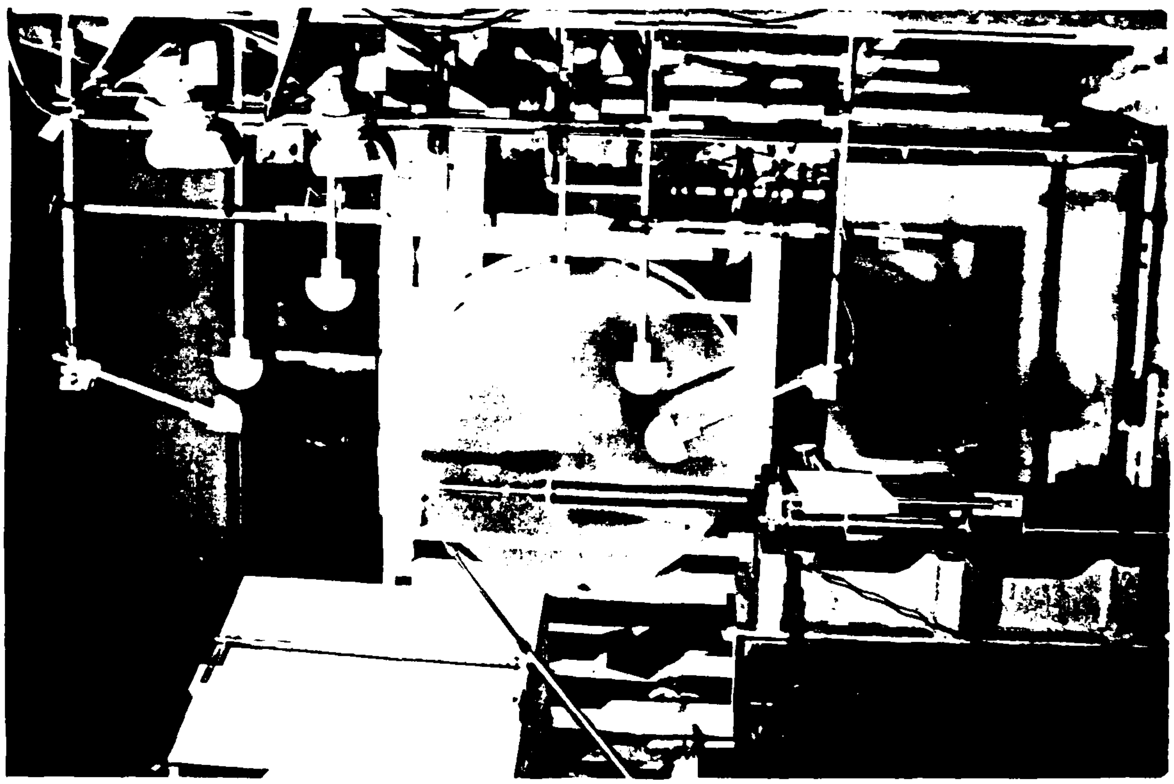

Figure 2. Photograph of Test Setup

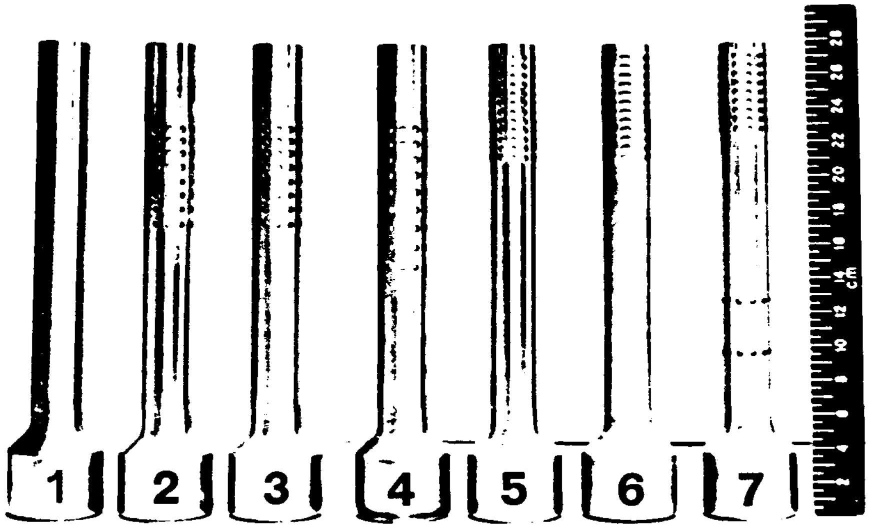

Figure 3. 20mm Perforated Muzzle Brake Devices

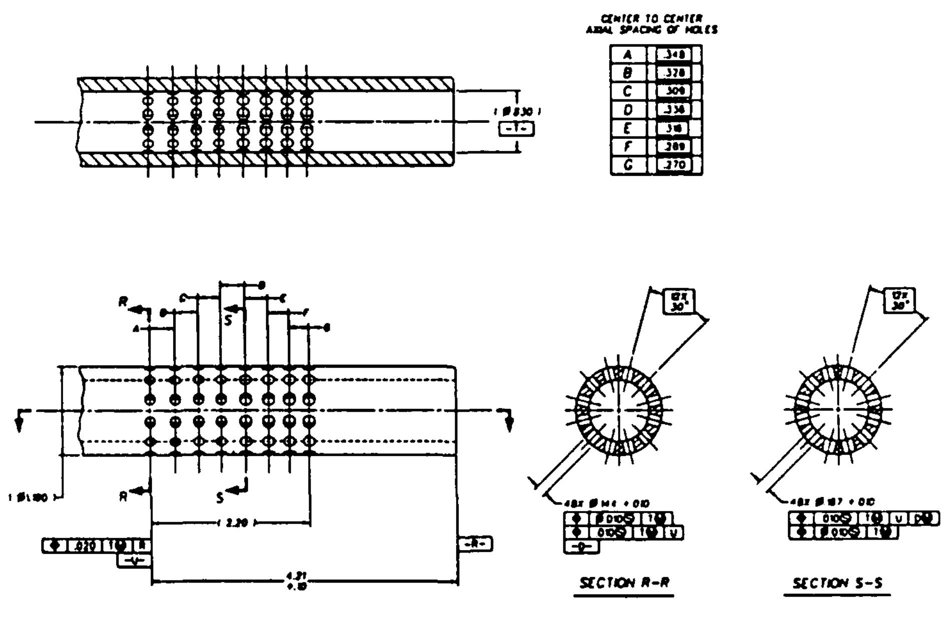

Figure 4. Drawings for Device 2

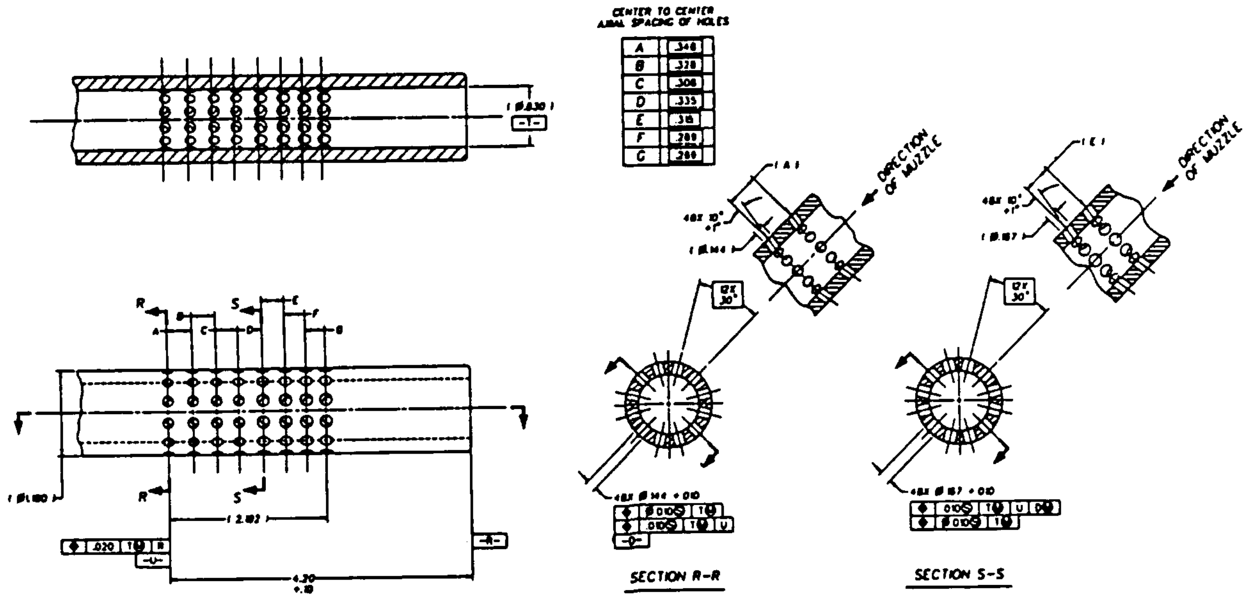

Figure 5. Drawings for Device 3

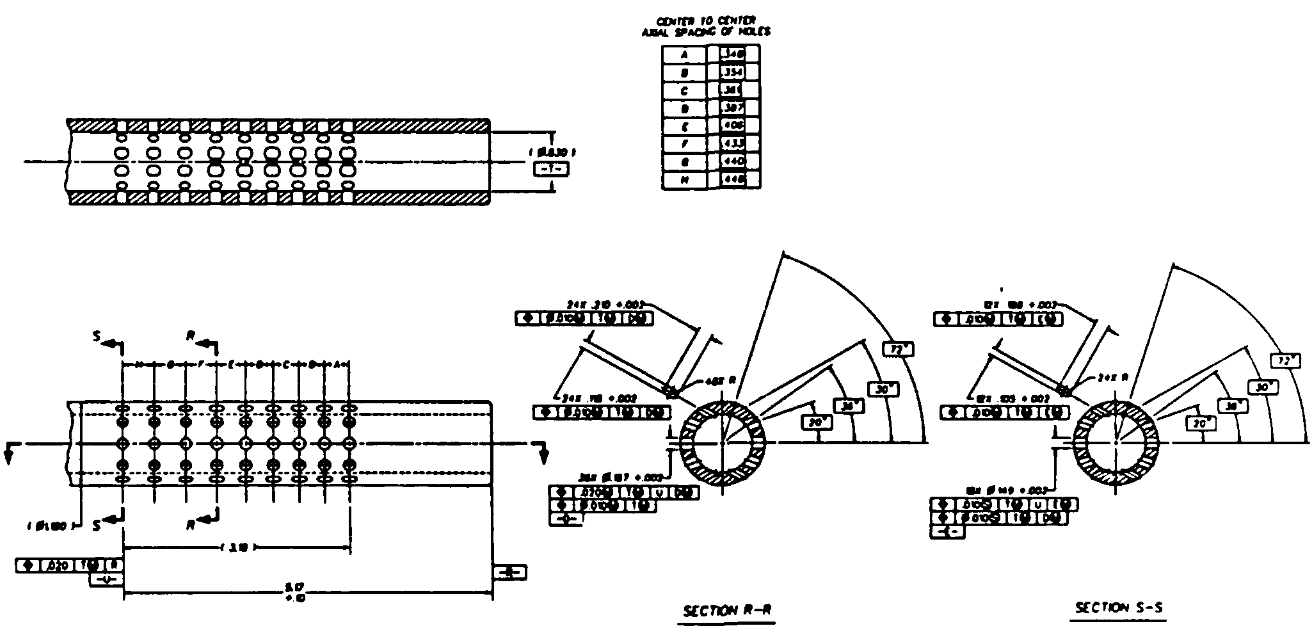

Figure 6. Drawings for Device 4

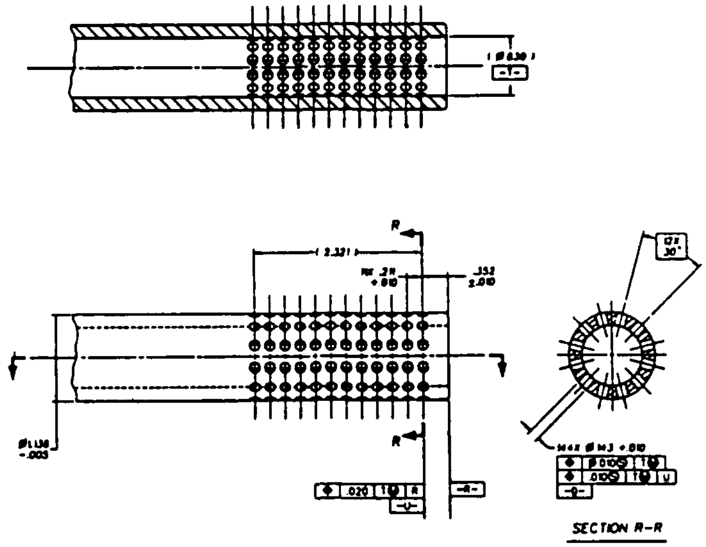

Figure 7. Drawings for Device 5

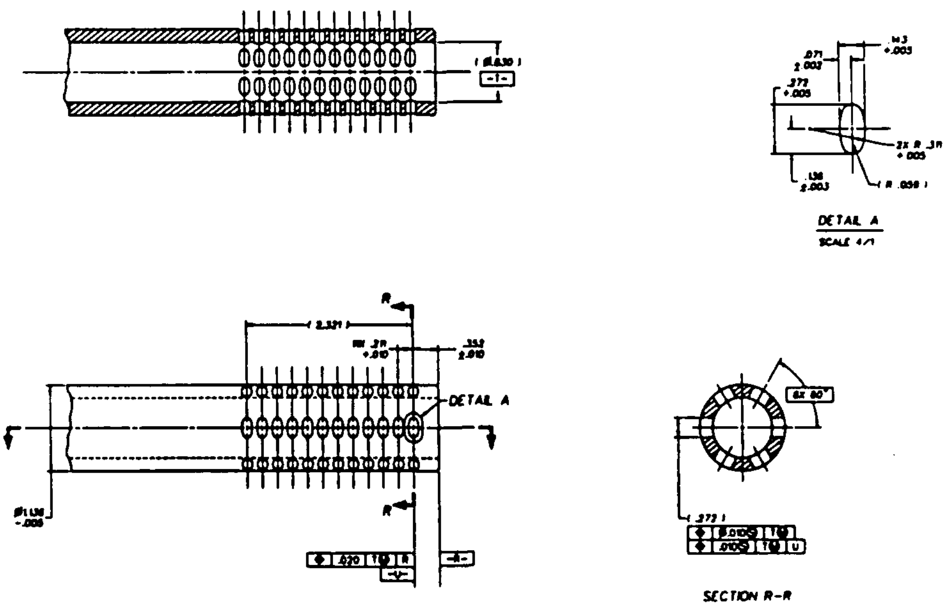

Figure 8. Drawings for Device 6

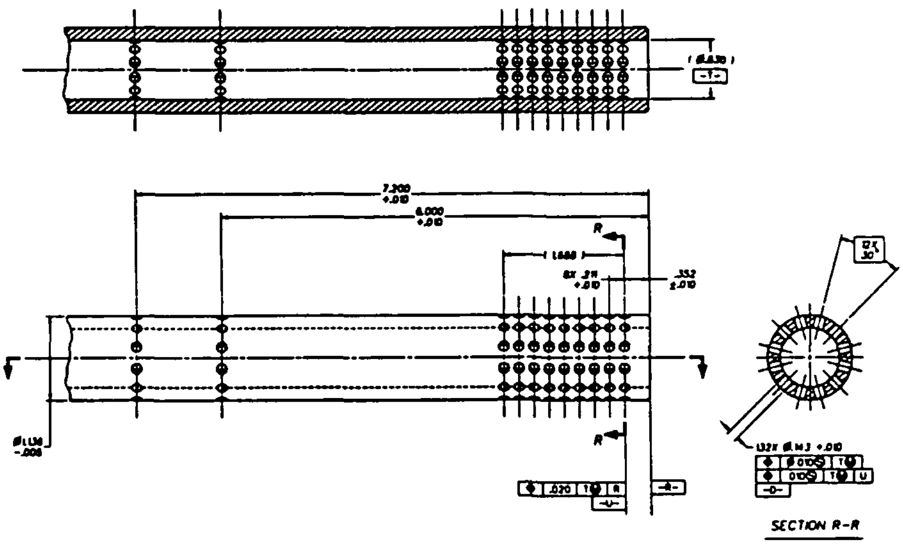

Figure 9. Drawings for Device 7

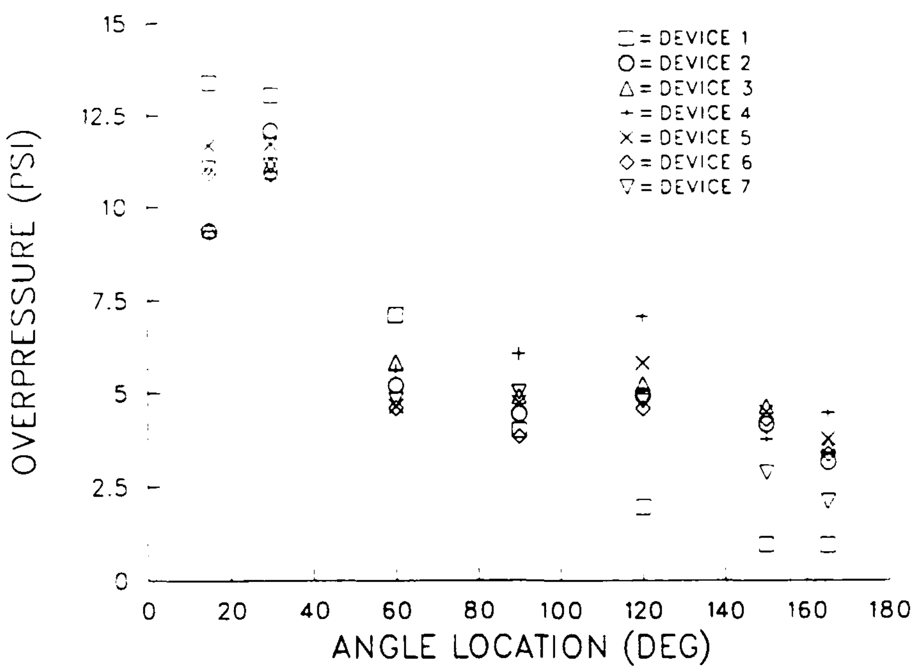

Figure 10. Blast Peak Overpressure at 30 Calibers from Muzzle

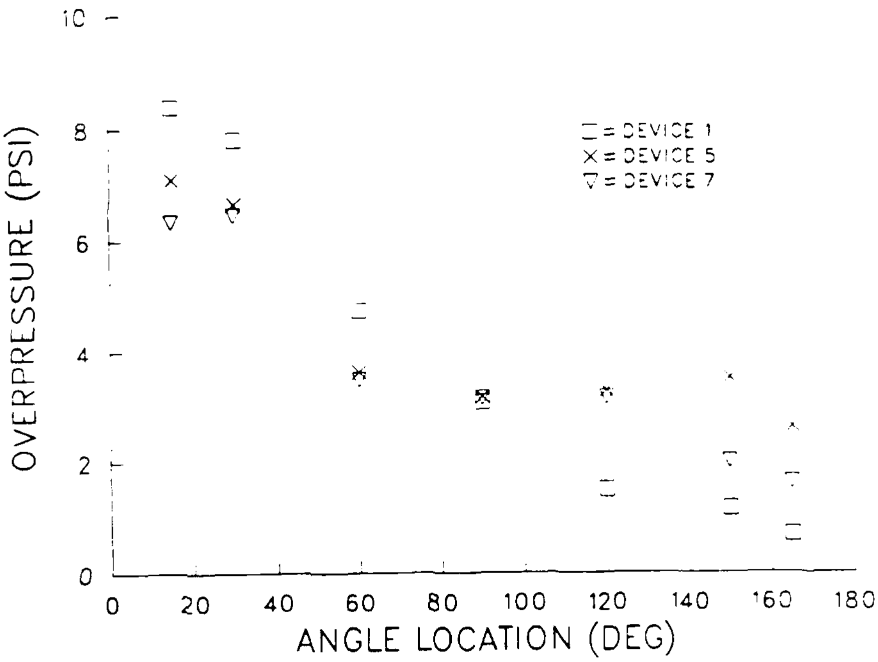

Figure 11. Blast Peak Overpressure at 40 Calibers from Muzzle

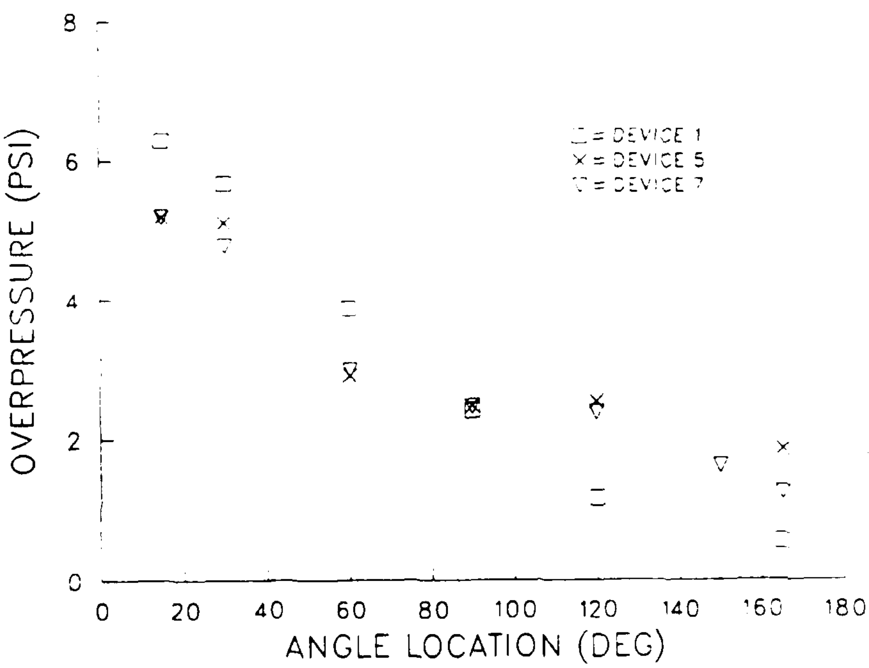

Figure 12. Blast Peak Overpressure at 50 Calibers from Muzzle

Figure 13. Shadowgraph of Blast Waves from Device 4

Figure 14. Shadowgraph of Blast Waves from Device 7

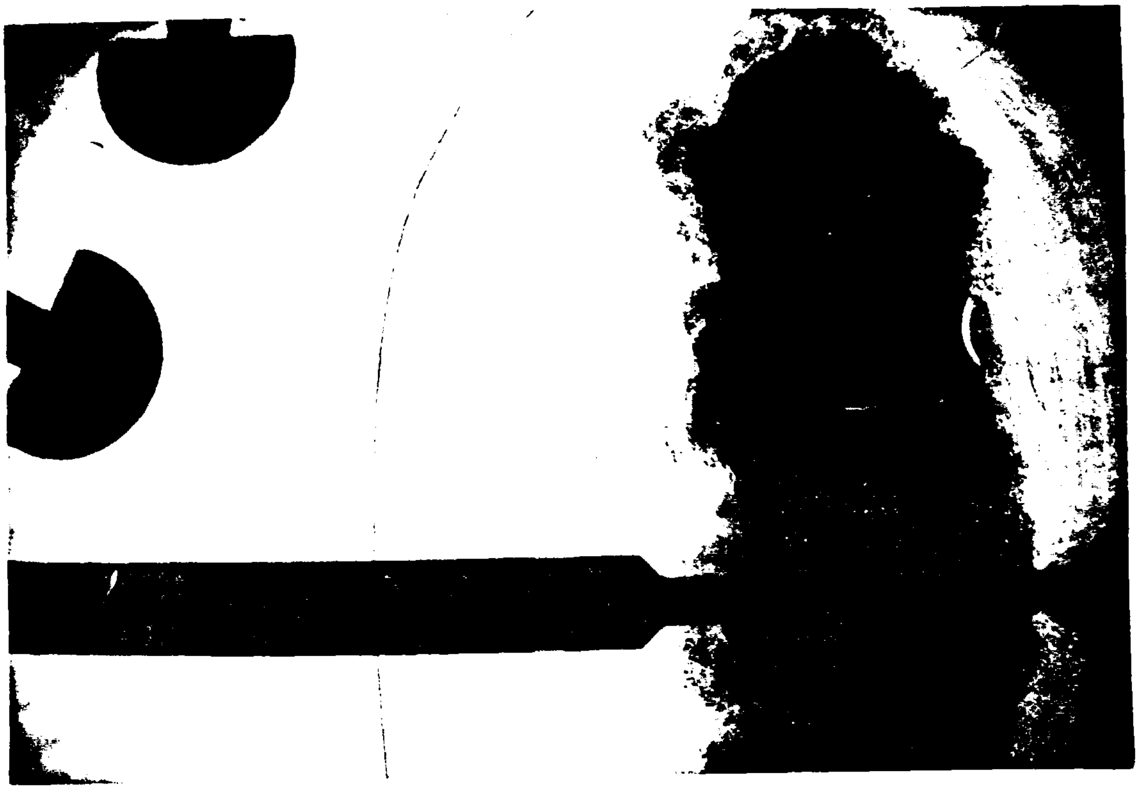

Figure 15. Blast Wave from Device 5 Traveling toward [illegible]

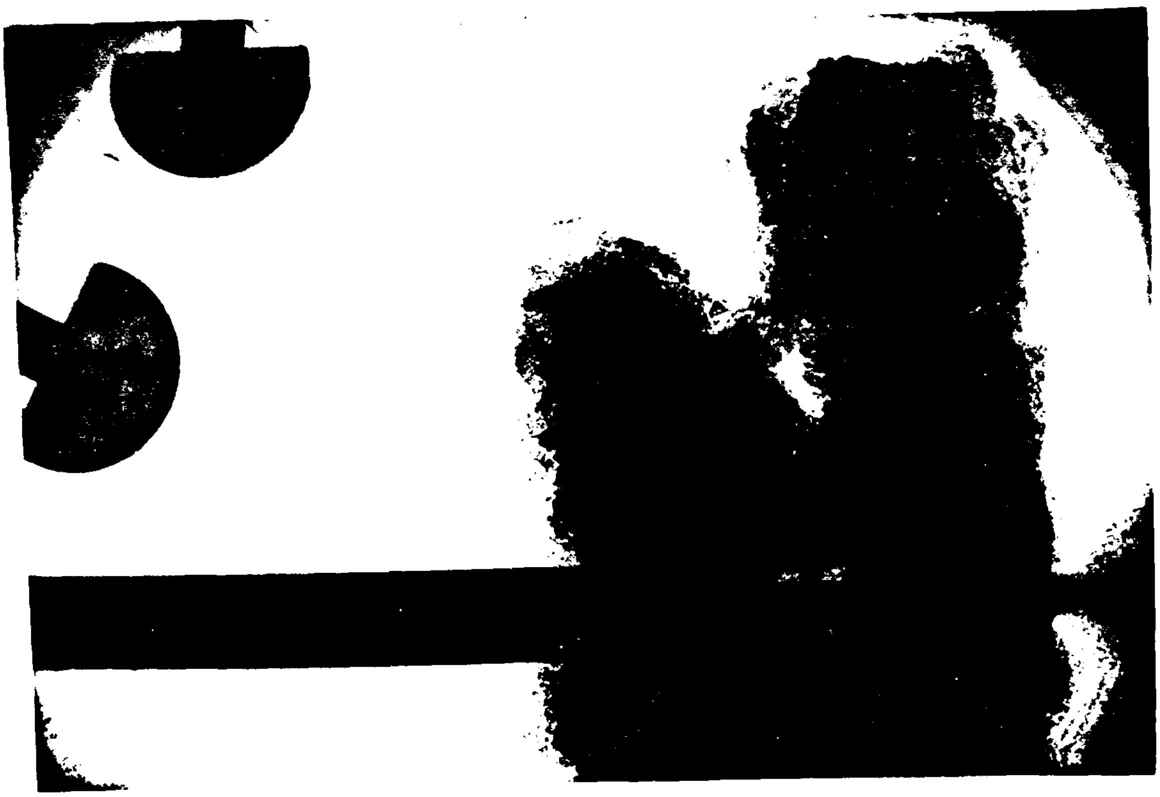

Figure 16. Blast Wave from Device 7 Traveling toward [illegible]

Device	X-ray Velocity (m/s)	Light Screen Velocity (m/s)
1	1058	1059
2	1062	1059
3	1059	1056
4	1056	1059
5	1061	1060
6	1056	1062
7	1058	1058

Table 1. Effects of Brake on Muzzle Velocity

	20mm	20mm	105mm	105mm	120mm	120mm
Device	ψ	β	ψ	β	ψ	β
2	15.8 %	51.5 %			46.3 %	99.6 %
3	17.4 %	56.4 %			47.0 %	101.2 %
4	16.5 %	53.6 %			51.8 %	111.4 %
5	19.2 %	62.5 %	32.0 %	67.0 %		
6	18.3 %	59.5 %				
7	19.1 %	62.3 %				

Table 2. Recoil Efficiency

8. References

1. Carofano, G.C., "Blast Field Contouring Using Upstream Venting", 4th International Symposium on Computational Fluid Dynamics, U. of California-Davis, Davis, California, September 9-12, 1991.

2. Braun, W.F., "The Free Flight Aerodynamics Range," BRL-R-1048, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, August 1958. (AD 202249)

3. Savick, D.S. and E.H. Baur, "120mm Perforated Muzzle Brake Performance", BRL Memorandum Report BRL-MR-3816, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, 1990. (Confidential)

4. Baur, E.H. and J.C. Ford, "A Parametric Study of Muzzle for Small Caliber Automatic Rifles", BRL-TR-3234, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland, May 1991.

5. "Logistics - Complete Round Charts", DARCOM Pamphlet 700-3-2, U.S. Army Material Development and Readiness Command, Alexandria, Virginia May 1984.

6. Plostins, P. and Clay, W.H., "Performance of Light Weight 105 MM Cannon Designs", BRL Technical Report BRL-TR-2749, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD. 21005-5066, 1986. (Confidential)

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LIST OF SYMBOLS

β	Gas dynamic brake efficiency
I_w	Recoil impulse with brake
I_{wo}	Recoil impulse without brake
m_r	Mass of recoiling parts
m_p	Mass of projectile
ψ	Overall brake efficiency
V_r	Velocity of recoil system
V_e	Projectile muzzle velocity

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